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Abstract

This project was the thesis research for Bob Greaves. The thesis consisted of five main sections: i) an analysis of the broadband LFM sweeps from the Acoustic Reverberation SRP 1993 acoustics cruise, ii) a thorough synthesis of all of the geological data sets acquired in and around ARSRP Site 'A', iii) a study of idealized canonical models of monostatic backscatter from rough and laterally heterogeneous seafloors, iv) a study of the effects of large scale slope and large scale average sub-bottom velocity, v) the modeling results were used to construct a methodology for inferring bottom characteristics from the monostatic backscatter data and the methodology was applied to the 1993 acoustics data. Greaves' thesis showed that the backscattered signals observed in monostatic reverberation experiments are caused by scattering from wavelength-scale seafloor and sub-seafloor variations in the velocity and density. It also showed that scattering intensity is clearly a function of most seafloor characteristics, for example, average subseafloor velocity and density, large-scale slope, wavelength-scale rms amplitude and seafloor and subseafloor heterogeneity. This study has yielded a greater understanding of the true complexity of the scattered signal that is observed in monostatic reverberation experiments.

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24 November, 1998

Dr. Edward A. Estalote
Office of Naval Research, Code 321
Ballston Tower One
800 North Quincy Street
Arlington, VA 22217-5660

Dear Dr. Estalote:

This is my final technical report for Grant No: N00014-95-1-0506. The period of this grant was from 01 March, 1995 to 30 September, 1998. Total amount of the grant was $94,000. The purposes of this grant were: 1) "to characterize the variations in bottom topography and sub-bottom properties that control the scattering of low frequency acoustic waves", 2) "to develop theoretical and numerical techniques capable of predicting the low frequency acoustic wave field scattered from geologically realistic models of the bottom/sub-bottom environment", and 3) "to isolate from these scattering models the physical mechanisms which dominate the long-range reverberation from the seafloor". Research was carried out in accordance with the following Grantee proposals:

Date	Proposal Number	Amount
23 Dec 94	9421	$30,000
29 Aug 96	1541	$64,000

We chose initially to look at the match filtered traces of the broadband LFM sweeps from the Acoustic Reverberation SRP 1993 acoustics cruise. The method and results are discussed in detail by Greaves and Stephen (1997). The modeling is constrained by the geological data sets acquired in and around Site 'A'. Based on the geological data sets we prepared models of elastic parameters and density that we can use in our Numerical Scattering Chamber (NSC). The NSC predicts the monostatic backscatter that we would expect from a given model and this in turn is compared with the actual acoustic returns from the geological area.

This project was the thesis research for Bob Greaves. Bob successfully defended his thesis in June 1998 (Greaves, 1998). The thesis consisted of five main sections. The first section was the analysis of the broadband LFM sweeps from the Acoustic Reverberation SRP 1993 acoustics cruise (Greaves and Stephen, 1997). The second section was a thorough synthesis of all of the geological data sets acquired in and around ARSRP Site 'A' and a number of seafloor models were constructed based on the geological descriptions (Greaves and Stephen, in prep c). The third section addressed a study of idealized canonical models of monostatic backscatter from rough and laterally heterogeneous seafloors (Greaves and Stephen, submitted). A large suite of models addressing specific features of the seafloor were run. The fourth section studied the effects of large scale slope and large scale average sub-bottom velocity (Greaves and Stephen, in prep a). The fifth section used the modeling results to construct a methodology for inferring bottom characteristics from the monostatic backscatter data and applied this methodology to an interpretation of the 1993 acoustics data (Greaves and Stephen, in prep b).

Greaves' thesis has shown that the backscattered signals observed in monostatic reverberation experiments are caused by scattering from wavelength-scale seafloor and sub-seafloor variations in the velocity and density. This is an important result, because much of the previous interpretation of acoustic reverberation data has been in terms of large-scale seafloor characteristics that are much larger than the wavelengths of the insonifying field. It was shown in this thesis that large-scale features, in particular high-standing ridges with steep slopes, will generate the expected high backscatter intensities. However, the source of this scattering is not the slope but the exposed basaltic rough seafloor that is found on these ridge flanks. The large-scale slope acts to enhance the scattering intensity by increasing the local grazing angle, but the slope is not the "source" of the scattering. It is also clear from the results of this study that similar strong scattering can be generated in relatively low-slope areas if the seafloor is an exposed and very rough basaltic bottom. Such seafloor is expected in regions of young oceanic crust where sediment accumulation is negligible.

It has been shown that scattering intensity is clearly a function of most seafloor characteristics, for example, average subseafloor velocity and density, large-scale slope, wavelength-scale rms amplitude and seafloor and subseafloor heterogeneity. Some parameters, such as subseafloor velocity gradients and individual faults have no discernible effects on scattering. In general, the sensitivity of backscattering to the former parameters is such that they can each account for much of the signal variation in reverberation data. However, the apparent functional relationships between these parameters and the backscattered signals is non-linear in each case. This leads to the conclusion that a unique interpretation of monostatic reverberation data may not be possible.

Another important conclusion is that although subseafloor volume heterogeneity at wavelength scales can produce a strong backscatter signal if the seafloor is very smooth (for example, a smooth sediment bottom with lateral heterogeneity), when the seafloor is rough the effect of volume heteroegeneity on the backscattering cannot be distinguished from the seafloor scattering. In general, volume scattering effects, observed in the water column, are primarily generated by scattering from heterogeneity that occurs just below the seafloor, which is comparable to scattering from seafloor roughness.

This study has yielded a greater understanding of the true complexity of the scattered signal that is observed in monostatic reverberation experiments. Finite-difference modeling has proven to be a very effective technique for determining the sensitivity of scattering to variations in geological models. It is important to keep in mind that sound scattered from the earth does, in fact, carry information about the geological properties of the earth, even though interpreting such signals is a very complex process.

One product of this study is a test of Lambert's Law for low angle backscatter from the seafloor. Although Lambert's Law may work to explain observations, other functional relationships could work just as well. By considering the different geological provinces of the seafloor in more detail we provide a more accurate representation of back scattering than is currently being used in the fleet and at some Navy labs. The techniques developed in this work and the insights gained into scattering mechanisms will apply to a broad range of environments (including deep and shallow water and sedimentary and igneous bottoms) and over a broad range of frequencies (from 10Hz to over 100kHz).

If you have any other questions or need more information please let me know. We appreciated your support. Thanks.

Yours sincerely,

Ralph Stephen

Ralph Stephen

Papers published under Grant No: N00014-95-1-0506
(1995-1998)

Refereed Journals:

Greaves, R.J. and Stephen, R.A. **(1997)**. "Seafloor acoustic backscattering from different geological provinces in the Atlantic Natural Laboratory," J. Acoust. Soc. Am.

Stephen, R.A. **(1996)** Modeling sea surface scattering by the finite difference method. J.acoust.Soc.Am., 100, 2070-2078.

Greaves, R.J. and Stephen, R.A. **(submitted)**. "Low-grazing-angle monostatic acoustic reverberation from rough and heterogeneous seafloors," J. Acoust. Soc. Am.

Stephen, R.A. **(submitted)** Optimum beam widths for interface scattering problems. J. acoust. Soc. Am.

Greaves, R.J. and Stephen, R.A. **(in prep a)**. "The influence of large-scale seafloor slope and bottom velocity on low-grazing-angle monostatic acoustic reverberation." J. Acoust. Soc. Am.

Greaves, R.J. and Stephen, R.A. **(in prep b)**. "Interpretation of low-grazing-angle monostatic acoustic reverberation data using an 'effective Rayleigh roughness'." J. Acoust. Soc. Am.

Greaves, R.J. and Stephen, R.A. **(in prep c)**. "A detailed geologic model for Site A in the Atlantic Natural Laboratory." J. Acoust. Soc. Am.

Other Journals, Book Chapters and Conference Proceedings:

Stephen, R.A. **(1996)**. Modeling sea surface scattering by the finite difference method. In: King, D.B., Chin-Bing, S.A., Davis, J.A., and Evans, R.B. (eds.) Benchmark solutions in reverberation and scattering: Proceedings of the reverberation and scattering workshop, May 2-5, 1994. Naval Research Laboratory Book Contribution NRL/BE/7181-96-001 (U.S. Government Printing Office).

Theses:

Greaves, R.J. **(1998)** Seismic scattering of low-grazing-angle acoustic waves incident on the seafloor.," PhD Thesis, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution Joint Program in Oceanography.

Reports:

Stephen, R.A. and Swift, S.A **(in prep)** Numerical noise and artifacts in the numerical scattering chamber. Woods Hole Oceanog. Inst. Tech. Memo., WHOI-??-??, 57 pages.